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TECHNICAL NOTES

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No. 160

FITTINGS AND OTHER STRUCTURAL PARTS OF AIRPLANES.

By P. Eydam

From Technische Berichte, Vol. III, No. 6.

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL NOTE NO. 160.

FITTINGS AND OTHER STRUCTURAL PARTS OF AIRPLANES.*

By P. Eydam.

The strength and reliability of airplanes depend greatly on the careful design and manufacture of the fittings, couplings and other highly stressed parts. In designing these parts, attention must be paid to the possibility of supplementary stresses, which in certain cases are engendered only by alterations in form during flight or during the loading tests.

Since fittings are made with the smallest possible dimensions, for the purpose of saving weight, and autogenous welding is extensively employed, work on these parts must be carefully supervised, in order that they may not be weakened at specially stressed points by badly formed welds, nor the material burnt in the neighborhood of the welded seams.

Failures of fittings, which occur during strength tests, are due in part to faulty design, but more often to careless workmanship. Since the use of autogenous welding cannot be foregone in airplane construction, owing to its speed and simplicity, the possible weakening of stressed sections should be carefully avoided, and it is of special importance that welded seams should not be permitted to carry the load alone.

The possibility of this is evident from the fact that it has

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frequently happened that airplane parts which failed under test were altered, or replaced by new ones of improved design, by co-operation between the testing station and the factory. Such alterations, however, necessitate the expenditure of money, time and material by both parties, which outlay can usually be avoided by the exercise of sufficient foresight. In many cases, static tests produce no structural changes nor ruptures, whereas alternating stresses, vibration and the influence of the weather produce such conditions that rupture follows, although the parts had sufficient strength originally. The more important parts must, therefore, even when of proved strength, be occasionally tested for increased loads and also in order to avoid the possibility of defects creeping in during subsequent quantity production.

The following remarks relate to actual examples, which have been observed in strength tests on airplanes.

A. Fittings for Wing Spar Joints.— A shoe (Figs. 9 and 10) broke during the nose-dive test (Case C) at 99% of the required load, after undergoing strength tests A, B and D without noticeable alterations in form. The structure showed numerous welds. During the nose-dive test, the lugs securing the wing to the fuselage were subjected to a strong bending stress which proved too great for the welds at the base of the lugs and the latter were wrenched off. The sheet metal was also bent sharply back and broke with the lug (Figs. 11 and 12). It was found that the parts were only superficially connected by the welds, the seams being only

1 mm (.039") thick, as against a plate thickness of 2 mm (.079"). This fitting was, therefore, altered (Fig. 13) by inserting instead of the former spacing piece, an intermediate strip, which was held in place by the bolt through the spar, thus relieving the welds. This strip was a little thinner than the spacing piece, while the lugs were somewhat strengthened. With this method of construction, even an imperfect weld need not necessarily cause premature rupture. The original shoe weighed 170 g (6 oz) while the altered shoe weighed 31 g (1.1 oz) more. In the corresponding fuselage fitting (Figs. 14 and 15), the lugs were also strengthened (Fig. 16), the ends of these, in the interior of the fitting, being bent away from each other so as to substitute tension for bending stress in the material of the shoe and the welds. The weight of this fitting was increased from 173 to 198 g (6.1 to 7 oz).

In a coupling between an upper wing spar and the cabane (Fig. 17), the end was bent during Test B (gliding flight) and the eye-bolt fitting was subjected to a heavy bending stress toward one side. If the end of the shoe is once bent, the upper half of the fitting can be easily ruptured. In designing this part, it was evidently assumed that the load on the main bracing wires, transmitted to the spar, would be sufficient to counteract the bending moment from the load in the end portion of the fitting. In order to reduce the bending stress, the eye was brought nearer to the base, and the transition from the rim to the eye was made more gradual, thus reducing the shearing stress near the rim. Abrupt transitions must be avoided in all such fittings. It is better in

every way to weld the eye-bolt all around to the shoe and not to limit the union to one or two points.

It is frequently the case that the tensile load between the spar joints of the lower wings, is not sufficiently taken up by the transverse members of the fuselage. Tension bands or compression tubes, which at the same time take up the load when landing, are, therefore, recommended for use with wooden fuselages. These must, however, be so connected to the fittings to which the spars are coupled as to obviate the possibility of any bending stress being set up by the attachment. Often the tension members did not lie in the plane of the stress, so that rupture resulted through the supplementary bending moments. The tension member in Fig. 18 shows a defect of this kind. This member consists of straps across the fuselage, so as to give additional stiffening, said straps being connected to the fuselage fittings by bolts. Since these bolts lie outside the direction of tension, bending moments arise. The lugs, through which the bolts pass, bend and the bolts break. The straps must either be connected so as to bring the bolts into the same plane or they must be replaced by wires with turnbuckles.

B. Fittings for Strut Connections.— Eye-plate fittings have frequently failed, both under test and during flight, the fitting usually bending at the holes in the flange plate (Figs. 19 and 20). Owing to the oblique direction in which the tension in the wire acts, one edge of the rim of the eye-plate base is pressed into wood, while the other side bends up the flange plate, the eye-plate

usually shearing through, chiefly because the transition from the base of the eye-plate to the lug is abrupt. These eye-plate fittings are fundamentally unsuitable for taking up loads in an oblique direction and it would be better to dispense with them entirely in the future.

Since it is difficult to ascertain the forces arising in these fittings, experiments for the purpose of determining suitable dimensions for eye-plates and flanges were tried with two different types (Figs. 21 and 22). Each fitting was attached to a spar (Fig. 23) and subjected to a load P acting at an angle of 45° . The results of the tests are given in Table I. With an eye-plate of 25 mm (.98") base diameter and 2 mm (.079") thick deformation began at 1000 kg (2205 lbs) and the eye-plate sheared through at 1500 kg (3307 lbs). When the flange was made 5 mm (.197") thick, deformation first began at 1500 kg and the rupture limit rose to 1880 kg (4145 lbs). Here also the eye-plate was the first to give way. Tests with eye-plates of 25 mm bore gave no better results. The last three tests showed that the breaking load did not increase in proportion to the thickness of the plate, but remained comparatively small for the thicker plates.

The connections were improved by increasing the thickness of the lugs from 1.5-2 mm (.059-.079 in.) to 2.5 mm (.098 in.), the eye-plates being made the same thickness.

In attaching the fittings to the spars, the plates are usually set into the spar, or into the plywood with which it is covered (Fig. 22). This method depends too much on careful workmanship,

and it has often happened that the base was not accurately fitted so that the plate was bent while being screwed into place. It is, therefore, better to place a suitably shaped metal piece under the plate (Fig. 24).

In the next fitting (Fig. 25), the bending moments were advantageously reduced by placing the balls in sockets which were pressed out of the plate, comparatively deep. The spar was bored through at the neutral axis and completely enclosed by the fitting, so that the forces were uniformly distributed throughout. Sufficient play had to be allowed in the holes through which the bolts passed, in order to prevent the latter being bent. For this reason, the holes were somewhat elongated. The fitting weighs 560 g (19.75 oz), but can be lightened by modification in several ways.

In a strut fitting with shackle and wire attachments (Figs. 26 and 27), the eye of the drag wire was wrenched off during the sand loading test for head resistance. The eye did not lie in the direction of the tension in the wire or cable and was, therefore, subjected to excessive stress. Should the drag wire be attached at another point, this connection could be recommended as being suitable and light. In many cases, the shackle bolts were bent (Fig. 28), thus causing rupture.

The usual construction (Fig. 29) is capable of much improvement. Even when the shackle plate is cut away at the middle of the bolt (Fig. 30), the latter can carry nearly 1.5 times the load. The form shown in Fig. 31, owing to a further decrease of the

bending moment, can carry almost double the load. The bent form, however, is shown in Fig. 32. This shackle can take 6.5 times the load of an ordinary shackle (Fig. 29), if k_s is made equal to $0.66 k_b$. Shackles of this type have breaking strengths up to 3400 kg (7496 lbs). In this case, the shackle plate tore and the bolt began to shear, as can be seen in the illustration on the left of Fig. 28. A load of 1500 kg (3307 lbs) was acting in the opposite direction. In no case was deformation of the shackle itself observed. In a shackle of the old type (on the right of Fig. 28), the bolt bent under a load of only 1800 kg (3968 lbs).

In the otherwise efficient strut attachment for all-metal airplanes (Fig. 33), owing to insufficient play between the strut and the fork, the former is subjected to a bending stress when the wings sag, with the result that the strut eye is bent, and the strut may break. The strut eye must, therefore, be thickened.

Figs. 34 and 35 show the construction of a strut fitting of a foreign machine. In this design all forces are transmitted to one spot on the neutral axis of the spar. The unsatisfactory feature here is the necessity for boring a second hole in the spar. It would be better to have the fitting enclose the spar. In another light and simple strut fitting on a foreign airplane (Figs. 36 and 37), the strut pressure is transmitted directly to the bracing wire, assisted by the upward bend of the plate lugs. The spar is drilled through the neutral axis. The Handley-Page airplane also shows carefully designed fittings (Figs. 38 and 39).

Sleeve connections are used throughout, being attached to the spars by bolts through the neutral axis.

In the light and efficient fitting shown in Fig. 40, attention must be paid to the flanging of the bracing wire lugs, to ensure that they are not too shallow. In several cases, the lugs were so short as to prevent the bolts from fitting properly, with the result that they were subjected to bending stresses.

G. Internal Bracing.-- Since the internal bracing of the wings is subjected to heavy stresses due to head resistance (Case C), the rigidity of the wing can be greatly increased by the careful construction of this bracing. In one instance, by diminishing the area braced, increasing the surface of the fitting in contact with the spar and slightly strengthening the spars, the strength to resist head loads was eventually made adequate. Defects in this direction must, however, be discovered and eliminated in the shops, by preliminary tests or strength calculations, in order that extensive alterations may not be necessary after the delivery tests. One fitting (Fig. 41) was bent during the test for head resistance, owing to insufficient width of the strap around the spar. The width of the strap around the spar should be at least equal to half the circumference of the spar. The insignificant increase in weight is more than offset by the increased stiffness of the wing. The eyes of the lugs for the internal bracing frequently break off and need subsequent strengthening.

D. Bracing Wires.— The fracture of the smaller turnbuckles frequently happens, owing to the internally screwed sleeves being badly tapped, thus producing bending stresses in the screwed ends, in addition to the tension for which they are designed. In the steel turnbuckle shown in Figs. 42 and 43, the sleeve was so carelessly tapped, that the axis of the screw was bent out of center by a distance equal to the diameter of the screw. Under these circumstances, the additional stress in the plane of the eyes amounts to 1170 kg/sq.cm (16642 lbs/sq.in.), assuming the tensile load to be 120 kg (264.5 lbs), which corresponds to an increase of 50% in the breaking load on the thread. As the stress on the edges of the eyes is still greater, failure at this point is easily explained, especially if the parts are bronze. The eccentricity can be diminished by bending the screwed sleeve, but small screws can frequently be broken in this way. In turnbuckles with rounded eyes, fitting between the forks (Fig. 44), the pin is subjected to bending stress, though it should only be subjected to shearing stresses (Fig. 45).

Carelessly made splices are a frequent cause of trouble. Some factories only splice the outer layers of the cables, while others carry it also into the central portion. Although tests have shown that a splice may possess sufficient strength when only the outer layers are spliced, the safety of the splice in this case depends on the care exercised by the workman. Such splices gave way under load tests, the core being pulled out of the surrounding spliced layer. If the splice is carried through to the

core, defective workmanship occurs more rarely and can be quite easily discovered by external inspection.

Splices often broke because they were soldered, not with a soldering iron, as prescribed, but with the aid of a blow lamp, the wires being thus softened. The necessity of using an acid-free soldering liquid is also frequently overlooked. The liquid then remains between the wires, which in time corrode and lose strength.

Owing to complaints from the front, a number of splices by one factory were recently tested. While the permissible loss in strength at the splice is 10% of the strength of the cable, the strength of the splices investigated varied between 100% and 73.8% of the strength of the cable. Thus, in the case of the weakest splice, its breaking load was 1520 kg (3351 lbs), while that of the cable was 2062 kg (4546 lbs). Such splices are naturally quite insufficient. It was also found that hydrochloric acid was used in soldering the splices and that many of the soldered joints had corroded. This case shows that splicing needs especially careful supervision and that breaking tests on selected splices are absolutely necessary.

E. Control Gear.— A common form of strut fastening (Fig. 46), which serves to connect the horizontal tailplane with the fin, often fails under test. The fitting at the fin end bends under a very small load, thus subjecting the strut to a bending stress, which can be avoided by the use of double gussets, or, as is often

specified, by stay-wires between the elevator hinge and the fitting. Such connections are also dangerous, in view of the possibility of their being bent during the transportation of the airplane on ground vehicles and subsequently breaking under the normal load which they are supposed to carry during flight. The hinge joint attaching the rudder to the fin (Fig. 47) can be recommended as safe and practical. It weighs only 0.73 kg (1.61 lbs). Frequently these joints are made with only two eyes. In such a case, however, the bolt is subjected to a bending stress and, with large rudder loads, such joints have a tendency to jam. Since these hinge joints also make it easy to remove and replace the rudder, it is desirable that they should be employed more frequently for attaching the ailerons.

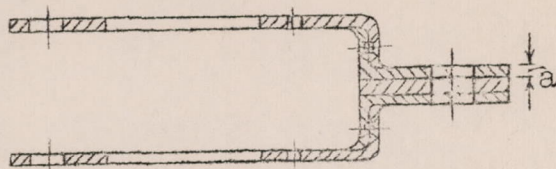
The structure of the ailerons is frequently too weak. Since they are subject to alternating loads and vibrations during flight, these parts should be particularly rigid. For this reason, it is also desirable to make the rib ends, between the rear spar and the trailing edge of the aileron, of box form. Then the often observed aileron failures would be avoided.

F. Landing Gear.— Owing to defective material, the majority of the axles tested bent considerably and some of them actually broke during tests. Collars, for taking the tension must, therefore, be shrunk on, and the use of screws for securing them in position should not be permitted, as the screw holes would weaken the axle and facilitate the development of dangerous fractures.

The amount of spiral wire spring used (some 30,000 meters (98425 feet) weekly) is far too great and should be considerably reduced, owing to the shortage of raw material. At the present time, the wire springs are fitted to the axle in a manner similar to that in which rubber cords were formerly applied and hence their elasticity is not sufficiently utilized. They should, preferably, be designed for either tension or compression, as, for example, in the arrangement of the axle springs on the A.E.G. airplanes.

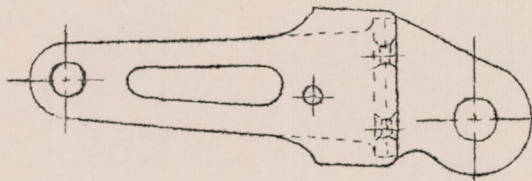
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Fig. 9 is the first figure in this note
Figs. 9, 10, 14, 15



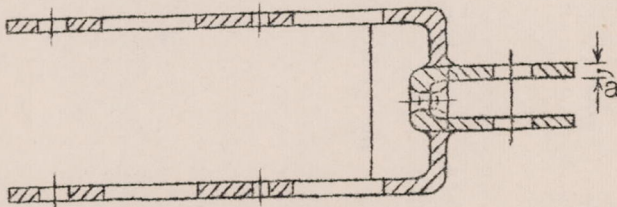
a 2.5 mm (.098 in)

Fig. 10



Weight 170 g (5.997 oz)

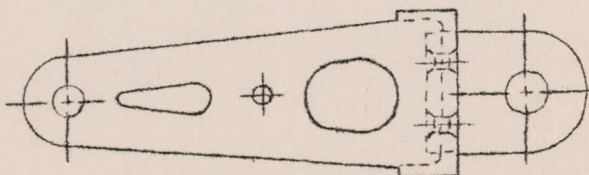
Fig. 9



a 2.5 mm (.098 in)

Old
construction

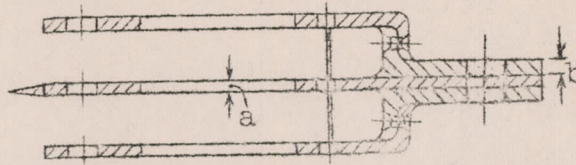
Fig. 15



Weight 173 g (6.102 oz)

Fig. 14 Fuselage fitting before modification

Figs. 13, 16, 24

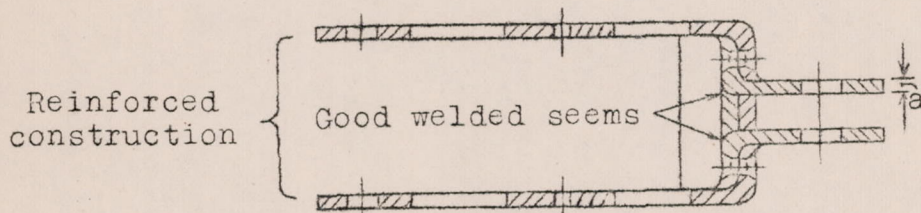


Weight 201 g (7.090 oz)

a 2 mm (.079 in)

b 3 mm (.118 in)

Fig. 13 Modified fitting



Weight 198 g (6.984 oz)

a 3 mm (.118 in)

Fig. 16 Modified fuselage fitting

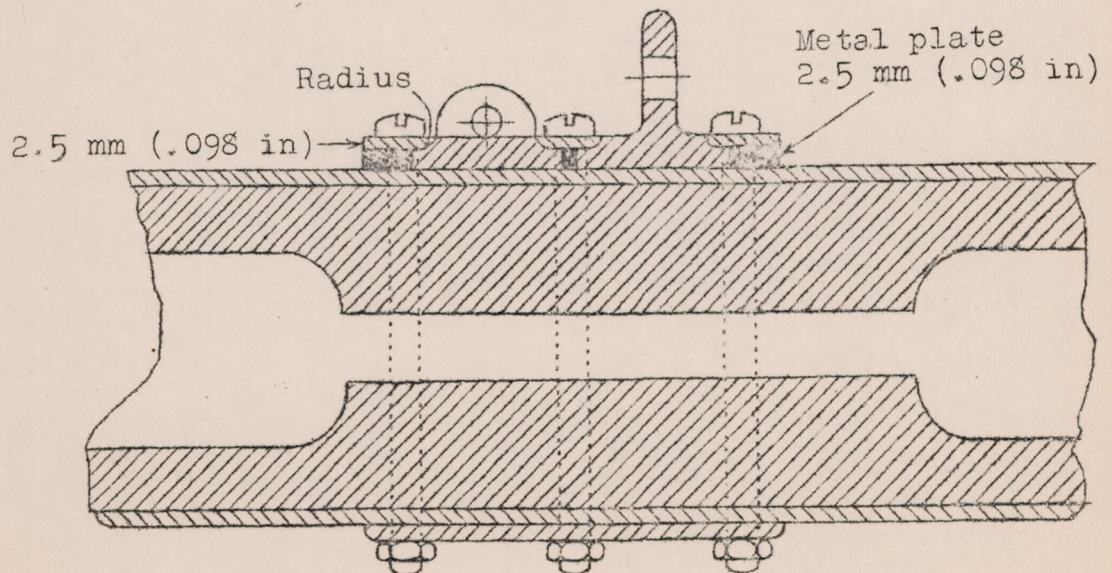
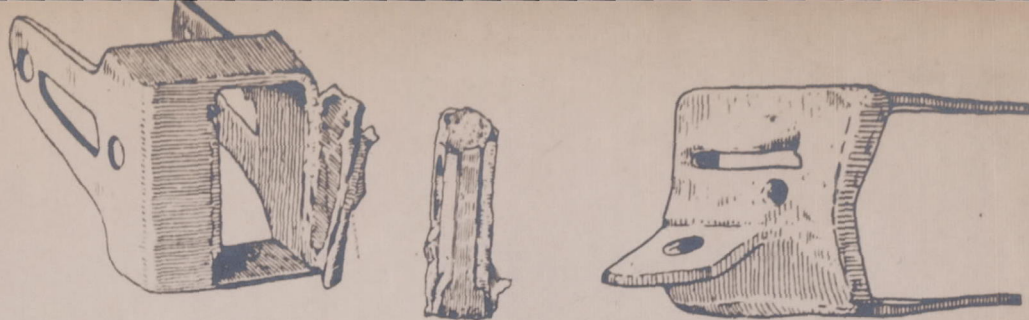


Fig. 24 Attachment of plate fitting to spar



Figs.11 & 12 Broken spar fittings

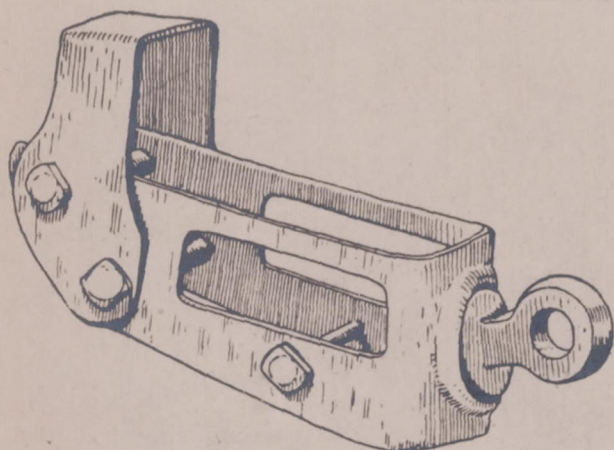


Fig.17 Coupling between upper wing spar and cabane

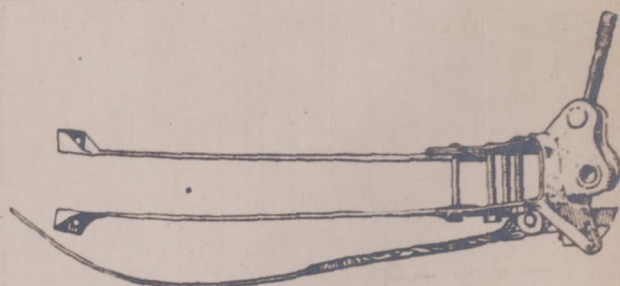


Fig.18 Tension strap connection

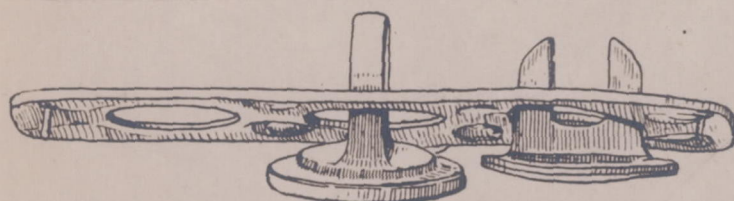


Fig.19 Deformed eyeplate fitting



Fig.20 Deformed eyeplate fitting

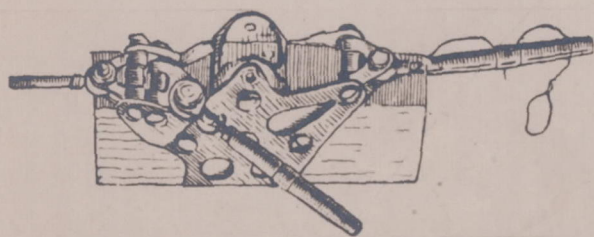


Fig.26 Strut end fitting

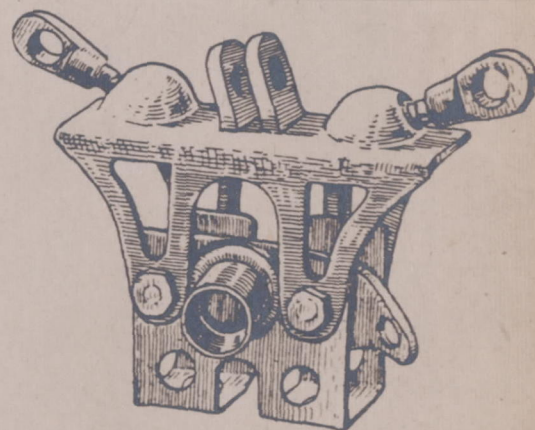


Fig.25

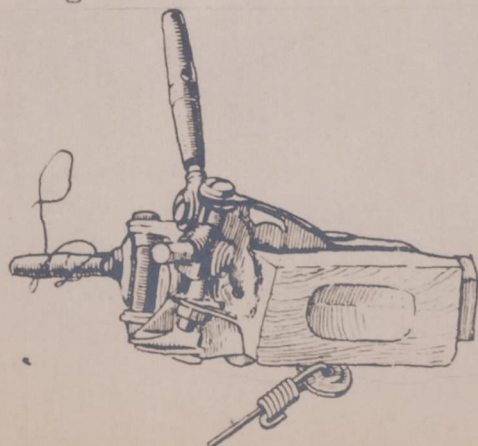


Fig.27 Strut end fitting

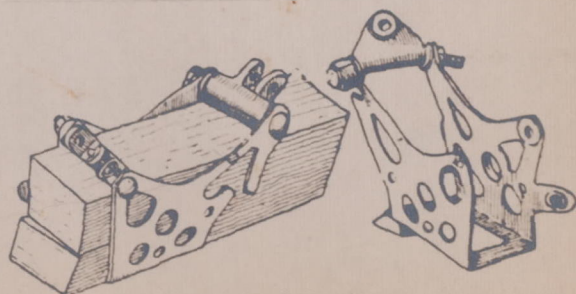


Fig.28 Bent shackle bolts

Figs. 21, 22, 23

Table I

Series	Eye-plate		Flange		Deforma- tion load kg	Break- ing load kg	Location of failure
	Base c mm	Thick- ness h mm	Thick- ness i mm	Center of eyes b mm			
I	25	2	4	60	1000	1500	Eye- plates sheared through
I	25	2	4	60	850	1340	
I	25	2	4.3	50	1350	1720	
I	25	2	5	50	1500	1880	
I	28	2.5	5.1	50	1500	1890	
I	28	3	5.1	50	1450	2020	
II	32	2	5.2	60	1400	2270	Flange plate fracture
II	32	3	5.2	60	1650	2650	
II	32	4	5.2	60	1750	3240	
	in	in	in	in	lb	lb	
I	.984	.079	.157	2.362	2204.60	3306.93	Eye plates sheared through
I	.984	.079	.157	2.362	1873.92	2954.19	
I	.984	.079	.169	1.969	2976.24	3791.95	
I	.984	.079	.197	1.969	3306.93	4144.69	
I	1.102	.098	.201	1.969	3306.93	4166.73	
I	1.102	.118	.201	1.969	3196.70	4453.33	
II	1.260	.079	.205	2.362	3086.47	5004.49	Flange plate fracture
II	1.260	.118	.205	2.362	3637.62	5842.24	
II	1.260	.157	.205	2.362	3858.09	7142.97	

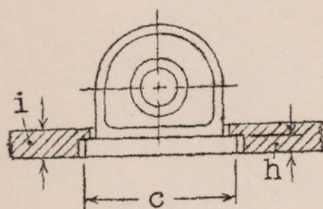


Fig. 21

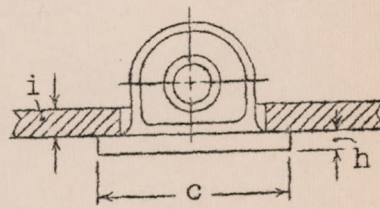


Fig. 22

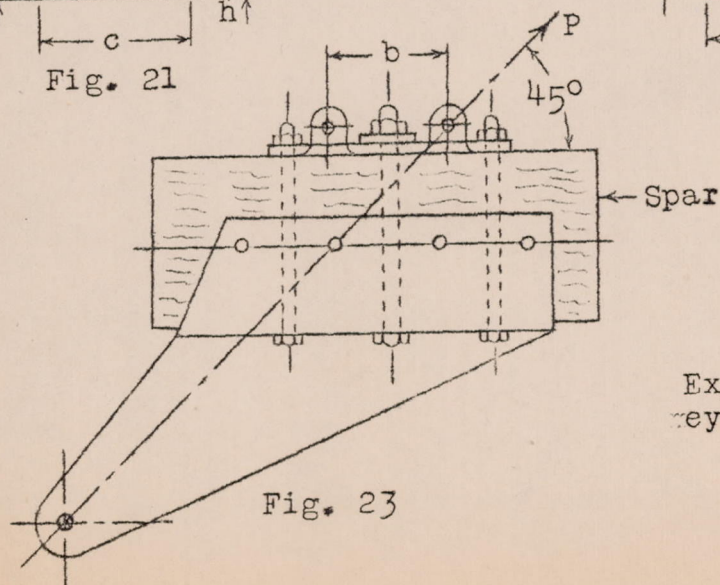


Fig. 23

Experiments with
eyeplate fittings

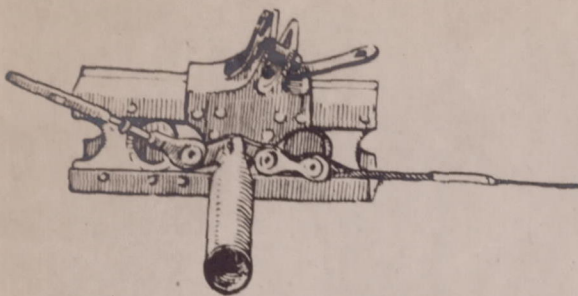
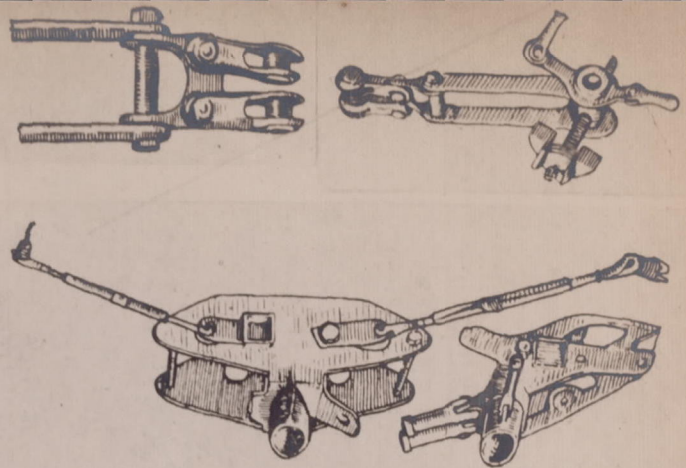
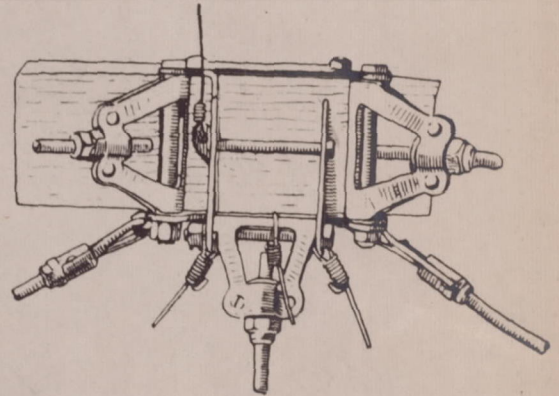
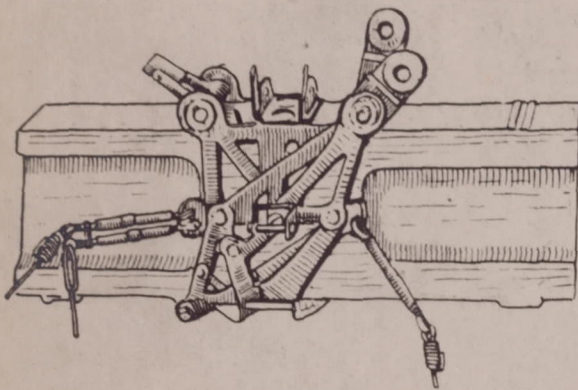


Fig. 33 Strut connections for all-metal airplanes



Figs. 34 to 37 Strut connections on foreign airplanes



Figs. 38 & 39 Metal fittings on Handley Page airplanes

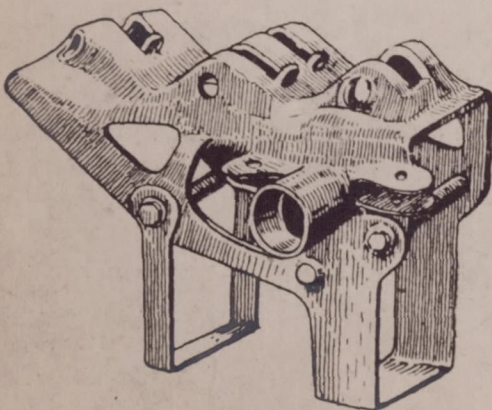


Fig. 40

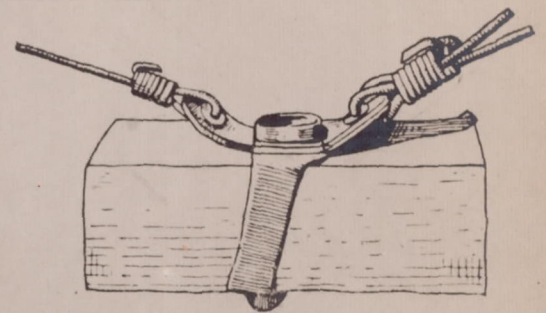


Fig. 41

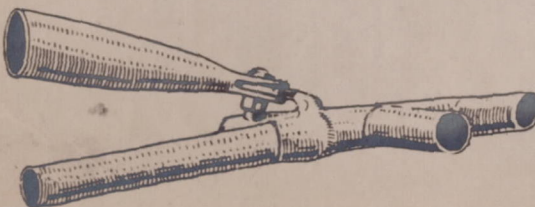


Fig. 46

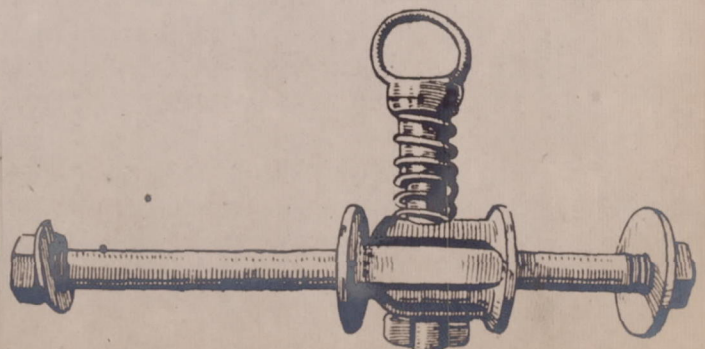


Fig. 47

Figs. 29, 30, 31, 32

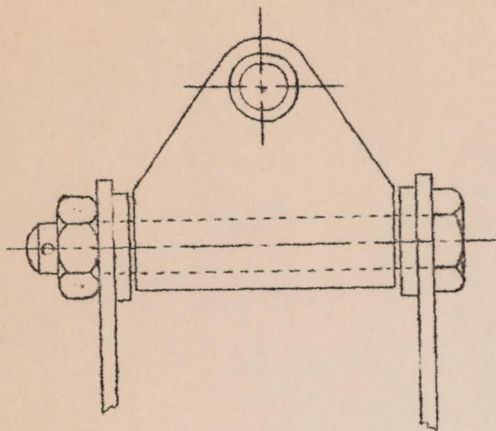


Fig. 29

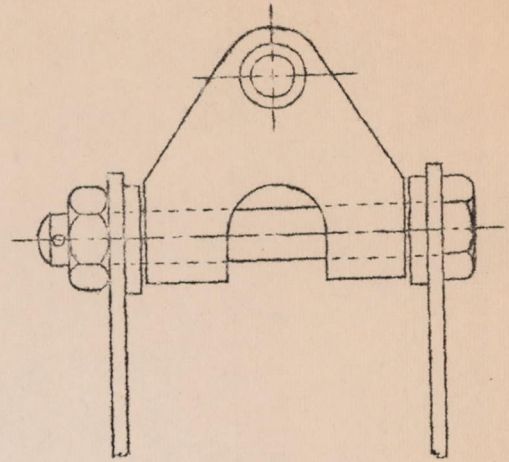


Fig. 30

Shackle designs

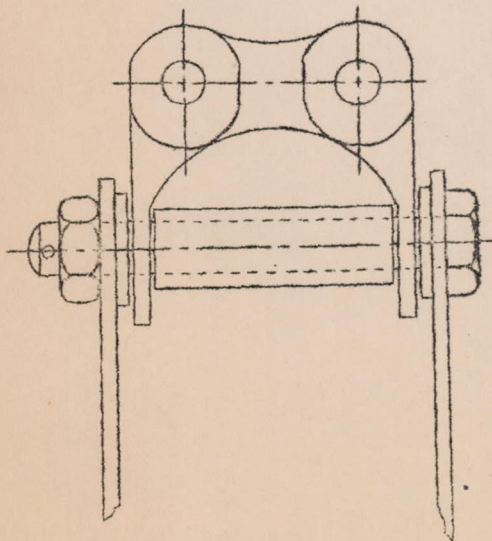


Fig. 31

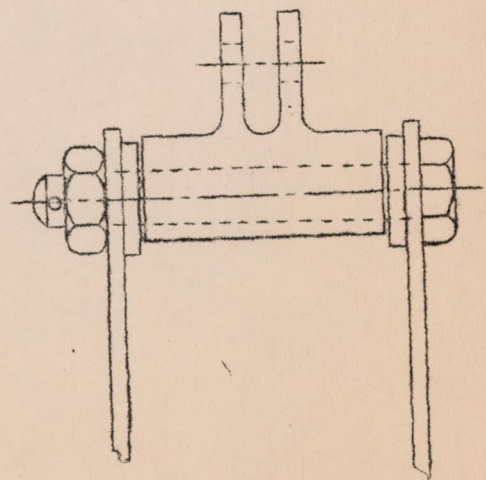


Fig. 32

Shackle designs

Figs. 42, 43, 44, 45

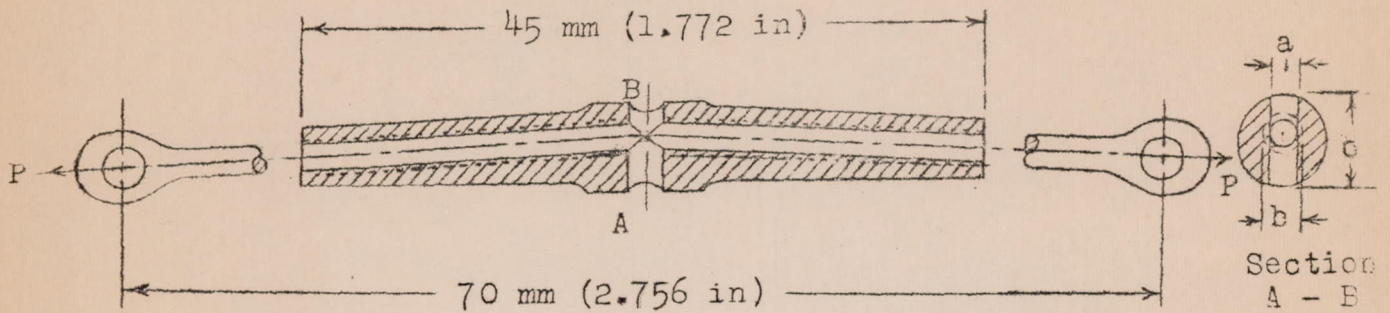


Fig. 42

Fig. 43

- a 2.5 mm (.098 in)
- b 3.0 mm (.118 in)
- c 5.5 mm (.217 in)

Turnbuckle

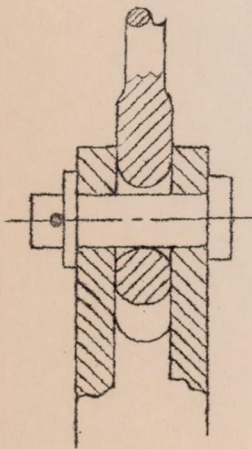


Fig. 44

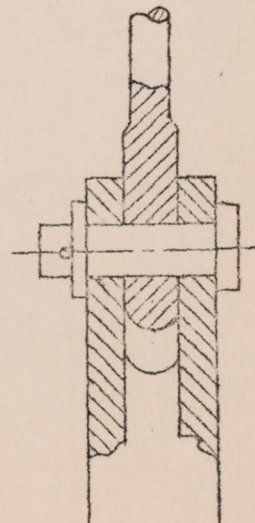


Fig. 45

Fork ends for turnbuckles